NACA

RESEARCH MEMORANDUM

COMPARISON OF EFFECTIVENESS OF COORDINATED TURNS AND LEVEL SIDESLIPS FOR CORRECTING LATERAL DISPLACEMENT DURING LANDING APPROACHES

By Stanley Faber

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
December 15, 1949

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

COMPARISON OF EFFECTIVENESS OF COORDINATED TURNS AND LEVEL SIDESLIPS FOR CORRECTING LATERAL DISPLACEMENT DURING LANDING APPROACHES

By Stanley Faber

SUMMARY

In order to determine which maneuver is more effective for correcting the lateral displacement from the runway during the final landing approach, the amount of possible correction was calculated for coordinated turns with limited bank angle and for level sideslips for a large transport airplane, the C-54D. The results of these calculations show that, for all distances from the end of the runway, coordinated turns are the more effective maneuver. At 2000 feet from the end of the runway, the correction possible in turns is roughly twice that in sideslips, and this ratio increases as the distance from the end of the runway increases. At distances of less than 1300 feet from the end of the runway, the amount of correction with either maneuver is almost negligible, being of the order of 20 feet or less.

INTRODUCTION

In discussions with pilots, the question of how to correct for the lateral displacement from the runway along an instrument glide path during the final approach has arisen. Two maneuvers were suggested, sideslips with the wings held level and coordinated turns. Some pilots felt that they would not bank a large airplane during the final approach and would only use the wings-level maneuver. On the other hand, flight records of simulated instrument approaches show that coordinated turns with limited angles of bank are more frequently used (reference 1).

Calculations have therefore been made to find which type of maneuver is more effective for correcting the displacement of the approach path for the condition when the airplane is very close to the end of the runway and at very low altitude. In the calculations the angle of bank during the coordinated turns was assumed to be limited to values less than that at which the wing tip would touch the ground before the main landing gear.

It was assumed in these calculations that the airplane was initially in a flight path parallel to the runway and laterally displaced from it. The flight paths of each of the maneuvers for various distances from the runway were then calculated. The results are shown as the locus of the starting points of the flight paths which would end at the runway center line. In the computations, the control response characteristics given in reference 2 for a large transport airplane, the C-54D, were used.

The results are of importance in blind-landing approaches in which the airplane breaks through the overcast 2000 or 3000 feet from the end of the runway and several hundred feet displaced from it. At these distances, during a normal instrument letdown, the altitude would be approximately 80 to 120 feet. If the pilot knows which maneuver is more effective, he may be able to land without making a second approach.

SYMBOLS

W	weight of airplane, pounds
V	velocity, feet per second
Y	total displacement in lateral direction from runway, feet
X	total displacement in longitudinal direction from end of runway, feet
ΔY, ΔX	partial displacement in lateral and longitudinal directions, feet
ϕ	angle of bank, radians
β	angle of sideslip, radians
ψ	angle of turn, radians
r	radius of turn, feet
a	lateral acceleration, feet per second per second
g	acceleration of gravity, feet per second per second

pb/2V	helix angle, radians
b	wing span of aircraft, feet
p	rolling velocity, radians per second
T	time, seconds

Subscripts:

1	initial
2	final

ANALYSIS

In the calculations of the amount of displacement that could be corrected by coordinated turns and by level sideslips, the following assumptions were maintained:

Airplane	C-54D
Conditions:	
Flap deflection, degrees	20
Gear	down
Manifold pressure, inches of mercury	20
Engine speed, rpm	2550
Wing loading, pounds per square foot	36.9
Airplane speed, miles per hour	120

Level-sideslip maneuver.- In this report the term "level sideslip" refers to the maneuver where the pilot uses the rudder to cause sideslip, keeping the wing level with the ailerons. The amount of displacement was calculated by assumming that the side force due to level sideslip is equal to the side force created when the airplane is in an equivalent banked, steady sideslip. In the steady sideslip the following relation exists:

$$\text{Side force} = W \sin \phi \approx W\phi$$

From figure 11(a) of reference 2, it was found that for the C-54D in the condition under consideration, ϕ is equal to 0.667β, therefore

$$\text{Side force} = 0.667\ W\beta$$

From this equation, it follows that the lateral acceleration is given by the relation,

$$\overset{a}{\alpha} = 0.667g\beta$$

and the lateral displacement is

$$Y = 0.667g \int_{T_1}^{T_2} \int_{T_1}^{T_2} \beta \; dT \; dT$$

These calculations are valid because only small changes in the flight path are involved; that is, the angle the flight path makes with the runway is small and the differences between the true side force and its calculated cosine component are slight.

The assumed complete maneuver (fig. 1) consists of the successive performance of one full-right and one full-left rudder deflection, followed by a brief amount of right rudder necessary to bring the airplane back to zero sideslip. The variation of the angle of sideslip with time was obtained from unpublished results of runs made in the C-54D where the pilot, while holding the wings level with the ailerons, changed the heading of the airplane with a constant rudder deflection. From the sideslip variation obtained in these runs, the sideslip variation of the assumed complete maneuver was found by superimposing, at the appropriate time, the sideslip variation obtained from a full-left rudder deflection on the sideslip variation obtained from a full-right rudder deflection. From this resulting sideslip variation the lateral displacement was calculated. The calculations were extended to cover different distances from the end of the runway by varying the time that full-right rudder was held with the length of time for full-left rudder and the brief right rudder being determined by the requirements that the airplane should end the maneuver at zero sideslip and with the original heading. These curves were graphically integrated and a locus of the starting points which would allow the maneuver to end at the center line of the runway was obtained.

Coordinated-turn maneuver.- To find the amount of lateral correction possible with this type of maneuver the flight path of coordinated right and left turns, performed in sequence, was calculated. In these calculations the flight path was broken into seven parts and each part was assumed to be circular. Figure 2 shows the maneuver broken into its parts. The parts are as follows:

(1) Period while controls are moved and the airplane begins to respond

(2) Period while the airplane changes from level flight to desired angle of bank

(3) Period while the airplane remains at desired angle of bank

(4) Period while the angle of bank is reducing during the change from bank in one direction to bank in other direction

(5) Period while the angle of bank is increasing during the change

(6) Period while the angle of bank remains at desired angle

(7) Period while the airplane changes from banked to level flight

The turning radius for each period was calculated from the expression that the side forces are equal to the centrifugal forces:

$$W \sin \phi = \frac{WV^2}{gr}$$

or

$$r = \frac{V^2}{g \sin \phi}$$

From the rolling-velocity curve, for an aileron roll with coordinated rudder deflection of figure 8, reference 2, the variation of the angle of bank with time was found by integration. From this curve the average angle of bank during each step was calculated. As a limiting condition, the maximum angle of bank was set at 17°, the angle of bank at which the wing tip and the main landing gear would both strike the ground at the same time. Shown in figure 2 is the variation of the angle of bank and the step approximation of the bank angle for a sample maneuver.

The angle through which the airplane turned during each portion of the maneuver was found from the expression $\psi = \frac{VT}{r}$.

Using this information, ΔX and ΔY of each period were found and added, giving the starting points of the maneuver. This type of calculation, rather than the integration method used for level sideslips, is necessary because the angles between the flight path and the runway are large enough to cause differences between the side force and its calculated cosine component.

The locus of the starting points was found for coordinated maneuvers using full aileron deflection and for coordinated maneuvers using enough aileron deflection to produce a rolling helix angle of 0.03 radian.

DISCUSSION OF RESULTS

The results of the calculations are shown in figure 3. It can be seen that the coordinated-turn maneuver will correct for a greater displacement than will level sideslips for all distances from the end of the runway. In fact, at 2000 feet from the end of the runway the possible correction in turns with maximum $pb/2V$ is roughly twice as much as that in sideslips with full rudder deflection and the ratio increases with increasing distances from the runway. At distances of less than 1300 feet from the runway, the possible correction in either maneuver is almost negligible, being of the order of 20 feet or less. This comparison is of maximum maneuvers, but since pilots do not usually use full control deflections in these maneuvers, the coordinated-turn curve corresponding to $\frac{pb}{2V} = 0.03$, a value obtained from flight records as the maximum pilots normally use, gives a better picture of the amount of correction possible. A portion of the level-sideslip curve using one-half rudder deflection is presented. The nature of the sideslip maneuver is such that the curve would approximately be a constant percent of the curve for full rudder deflection.

Of interest is the starting point of the shortest maneuver which reaches the maximum allowed bank angle of 17°. From figure 3, this point, when full aileron control is used, is at 1980 feet from the end of the runway, and for the more normal maneuver, at 3600 feet. This means that for $\frac{pb}{2V} = 0.03$ at less than 3600 feet from the runway, the airplane will never arrive at a steady-bank condition before the controls must be reversed, and that the airplane will always have its main wheels lower than its wing tip. Also shown in figure 3 is the path of the airplane approaching at a constant angle of bank of 17°. This path is the limiting one for flight paths which end alined with the runway.

The relatively small maneuvering capabilities of a large transport airplane in the final approach are apparent from this analysis. The maneuverability is further decreased by increases in size or wing loading above the values used in these calculations.

The maneuverability of a given airplane in sideslip may be increased by increasing the variation of side force with sideslip, which primarily depends on an increase in fuselage lateral area. Because of the large superiority of the coordinated-turn maneuver, however, it is unlikely that practical increases in side area would be enough to make the sideslip maneuver the more effective of the two. The maneuverability in turns may be increased by increasing the aileron effectiveness and by decreasing the moment of inertia in roll. These changes would allow the airplane to roll more quickly to the steady-bank condition, which would allow more time to be spent at short turning radius.

CONCLUDING REMARKS

Calculations have been made for a large transport airplane, the C-54D, to determine which maneuver, coordinated turns of limited angles of bank or level sideslips, is more effective for correcting the lateral displacement from the runway during the final landing approach. The results show that for all distances from the end of the runway the coordinated maneuver is the more effective maneuver. At 2000 feet from the end of the runway the correction possible in turns is roughly twice that in sideslips and the ratio increases as the distance from the runway increases. At distances from the runway of less than 1300 feet, the correction possible with either maneuver is slight, being of the order of 20 feet or less.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCES

1. Talmage, Donald B.: A Time History of Control Operation of a C-54 Airplane in Blind Landing Approaches. NACA RM L7F20, 1947.

2. Talmage, Donald B., and Reeder, John P.: Lateral and Directional Stability and Control Characteristics of a C-54D Airplane. NACA RM L8K30, 1949.

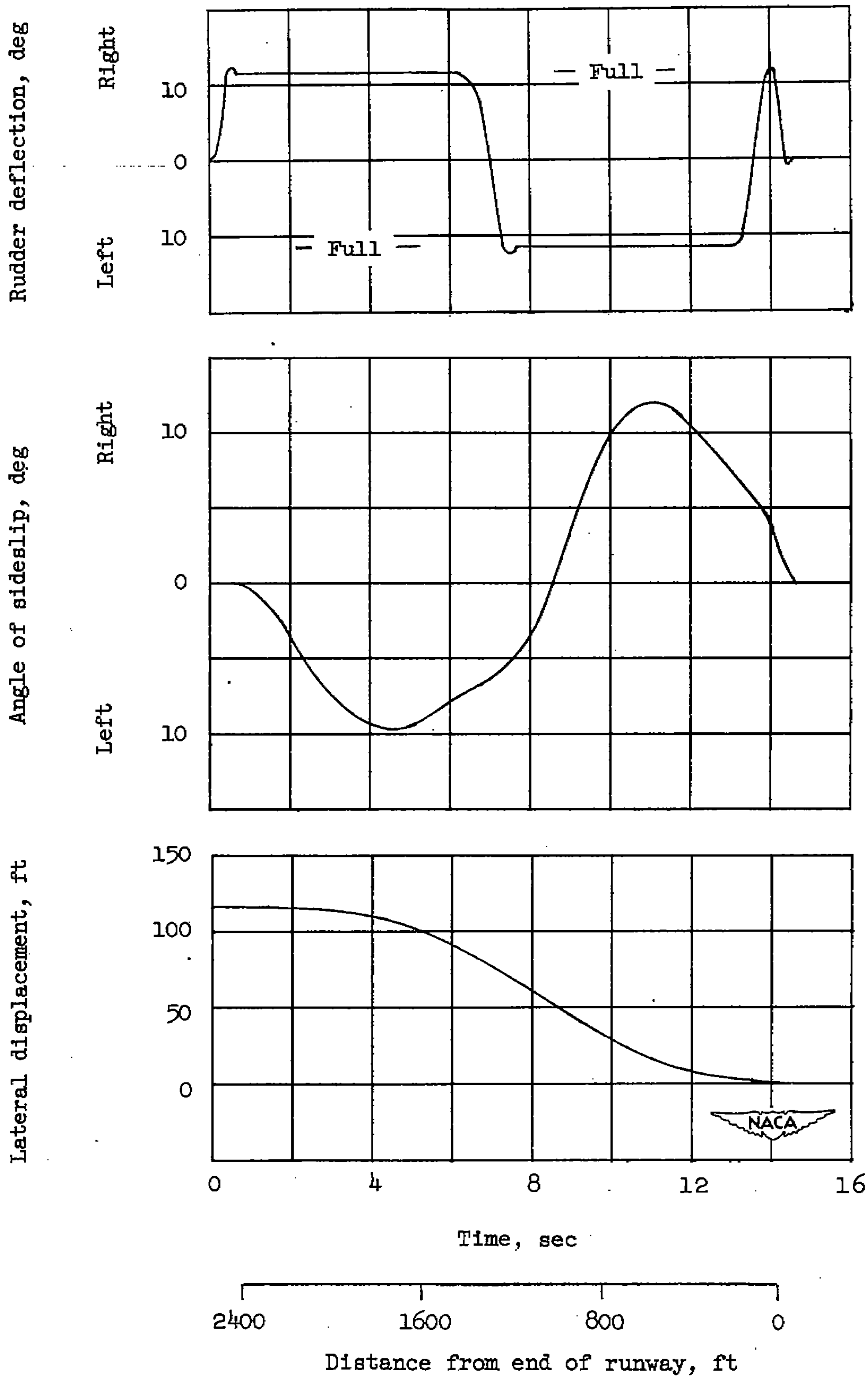

Figure 1.- Sample sideslip maneuver.

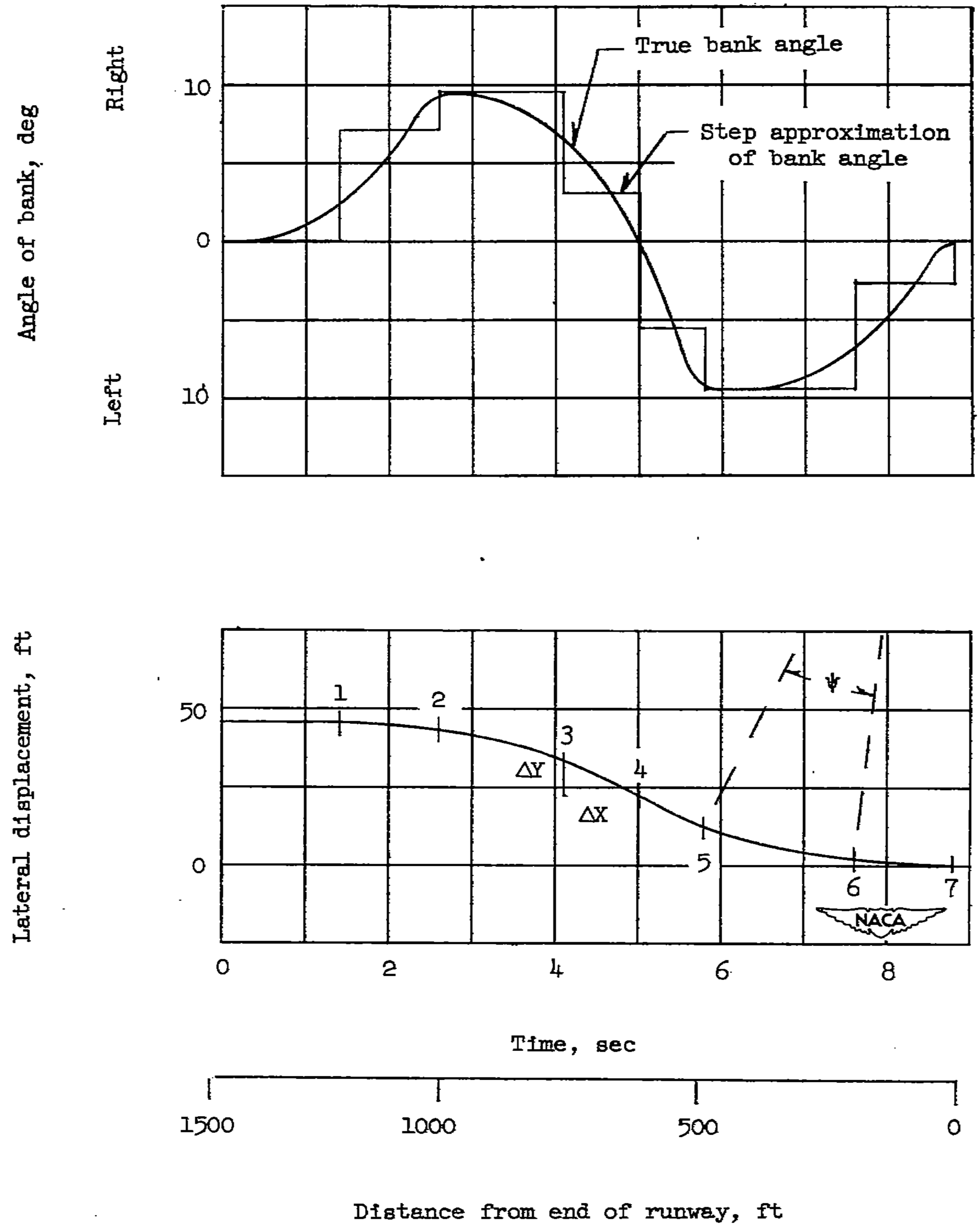

Figure 2.- Sample coordinated-turn maneuver.

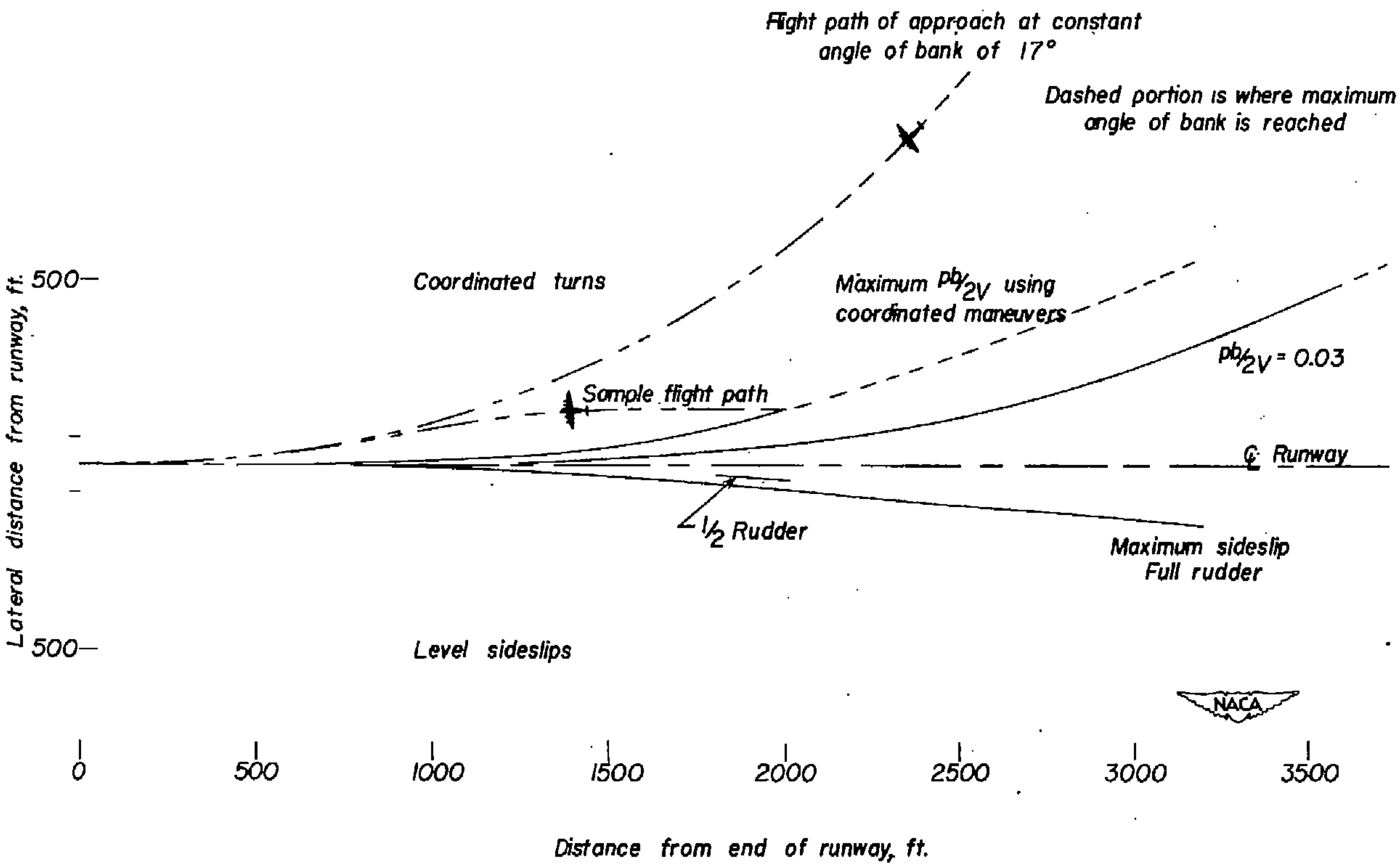

Figure 3.- Locus of the starting points of the maneuvers which would end at the runway center line.